Sex estimation of os coxae using DSP2 software

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Title: Sex estimation of os coxae using DSP2 software: a validation study of a Greek sample

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Abstract

Sex estimation methods based on skeletal remains vary on the selection of skeletal element, data acquisition and statistical approach resulting in variable classification accuracies that are highly dependent on the sample population. The only exception of this rule seems is the os coxa that appears to differ consistently between males and females across the globe. Currently sex based on the os coxa can be easily by estimated taking ten measurements, input these in the DPS2 software and get a sex estimate and the probability of correct group assessment. The performance of the software is highly reliable as confirmed by a validation study by Brůžek and colleagues (2017). Yet, there are still many populations not represented in the reference sample used to develop the software. The current study aimed to validate DPS2 using a sample from Crete, Greece. A total of 133 os coxae were measured following instructions on DSP2. Data were used to estimate sex with the software and to create population specific formulae for the Greeks. DSP2 classified 117/133 (85.7%) of the sample with over 95% posterior probability (PP) of correct classification. Of the individuals classified with over 95% PP, only 3 were misclassified (2.6%).The best population specific formula only improved this percentage by 2.1% which indicates that DSP2 is a reliable tool for sex estimation in the Greek sample and it is recommended as method of choice in sex estimation of remains of unknown ancestry. If Greek ancestry is confirmed, population-specific formulae can be used in conjunction with DSP2 for a more reliable sex estimation.

Key words: Forensic Anthropology, DSP2, sex estimation, pelvis, Greece

Introduction

Forensic Anthropology methods for estimating the biological profile of unidentified remains are increasing during the last decades focusing on different anatomical elements, different populations and various statistical procedures which are heavily scrutinised to fulfil the expectations of the court. Amongst the basic biological features sex is the most studied with several methods marking high accuracies [1–3]. Scholars agree that most osteometric methods are population specific [4–6] with the exception of the pelvis [1,7]. Female pelvis is constructed to facilitate both bipedalism and parturition, thus the shape is notably different compared to the male pelvis. The two selective forces in the female are somehow contradictory creating the so called *obstetrical dilemma* [8]: locomotion restricts the size of the birth canal which is expected to be large enough to accommodate an encephalized neonate. A recent study supports that human variation of the birth canal is geographically structured which is attributed by the authors to neutral evolution through genetic drift and differential migration [9]. The os coxae can be seen as an integrated unit consisting of two basic modules: a sacro-iliac module and an ischio-pubic module. Modularity helps to understand the evolution and plasticity of organismal form [10] and, consequently, the sexual dimorphism and its variation.

Shape and size differences between male and female pelvis, however, have long been noted and used for sex estimation in complete or portions of the os coxae [11,12]. The suggested lack of population specificity of the pelvis led researchers to develop a software (DSP2) that can predict sex based on measurements of the pelvis from over 2000 individuals and can give probabilities of correct group assessment [1]. The software, based on Discriminant Function Analysis (DFA) was validated with a large sample of 623 individuals from United States and Switzerland and resulted in classifying up to 90% of the sample with over 95% probability of correct classification. The DSP method has been validated in other dry bones samples of known age and sex (for example in a Mexican [13], a Belgian [14], a French [15] and a Brasilian sample [16]. The DSP method has also been validated in 3D models of os coxae obtained from CT scans in living French population [17] and on 3D CT scans from modern Danish population [18]. Yet, both the reference and the validation sample are missing numerous populations around the world which have to be tested before the method is used for forensic applications.

This paper aims to test the DSP2 software in a contemporary sample from Crete, Greece and thus confirm or reject the hypothesis of non-population specificity for pelvis as sex indicator. The results of the study will define the suitability of the DSP2 method for sex estimation in modern Greeks.

Material and Methods

Sample

A total of 133 os coxae (68 males and 65 females) from the Cretan collection [3,19]were used in this study. The left os coxa was used for consistency.

Data acquisition

The following measurements were taken by a single moderate experienced observer (LS) using standard osteometric equipment were used following Bruzek et al. [1].

Measurements

PUM (M14)- Acetabulo-symphyseal pubic length[20]
SPU- Cotylo- pubic width[21]
DCOX (M1)- coxal length [20]
IIMT (M15.1)- Greater sciatic notch height [20]
ISMM- Ischium post-acetabular length [22]
SCOX (M12)- Iliac or coxal breadth [20]
SS- Spino-sciatic length [21]
SA- Spino-auricular length [21]
SIS (M14.1)- Cotylo-sciatic breadth [20]
VEAC (M22)- Vertical acetabular diameter [20]

Error estimation

Error was estimated using technical measurement error (TEM), relative TEM (rTEM) and coefficient of reliability (R) of the measurement.

Validation of DSP2 software

Measurements were inserted in the DSP2 software and posterior probabilities were calculated automatically. The data were inserted in Excel for further analysis.

Data analysis

Variables were tested for normality and equal variances between the two groups (males and females) and parametric and non-parametric tests (e.g. ANOVA, Wilcoxon test) were used to explore if there are statistically significant differences between the sexes.
Univariate and multivariate discriminant function analysis was used to create population specific formulae for the Greek population. Posterior probabilities for correct classification were estimated.
Statistical analysis was carried out using SPSS 24.

Results

Error estimation

Intra-observer error was estimated using technical measurement error (TEM), relative TEM (rTEM) and coefficient of reliability (R) of the measurement. The results are illustrated in Table 1.
Table 1 here

Univariate statistics

Descriptive statistics of the 10 measurements and univariate differences between the sex groups are shown in Table 2. All variables were found significantly different between the sexes at the level of $p< 0.01$ with the exception of Sa that did not show statistically significant mean differences between the sex groups. Univariate discriminant functions were created and demarking points were calculated for each variable. Variables that presented over 80% overall classification accuracies are considered of forensic importance. These were Ismm, Spu,Dcox and Veac. Ismm exhibited the highest accuracy (86.4% for males and 85.9% for females) for both original and cross-validated data.

Table 2 here

Multivariate Discriminant Functions

Discriminant function analysis was conducted for different sets of variables. F1 used all variables for comparative purposes with the DSP2 analysis. F2 used all statistically significant variables (all except Sa) and F3 used a stepwise procedure for selecting the best variables for the estimation of sex. Stepwise procedure selected four variables, namely Pum, Spu, Iimt and Ismm. A forth function F4 was created using the four best single variables in terms of accuracy (Ismm, Spu, Dcox and Veac). All function coefficients are presented in Table 3. Sectioning point is set to zero in all cases. Classification accuracy is also presented for both original and cross validated data. The best classification accuracy for cross-validated data is achieved with stepwise procedure (F3, 93.5%).

Table 3 here

Posterior probabilities of correct classification were calculated using DSP2 and Functions F1 to F4 that were developed for the Cretan sample. DSP2 classified 85.7% of the sample with over 95% posterior probability (PP) of correct classification. Of the cases classified with over 95% PP only 3 (2.6%) were misclassified. (Table 4). The number of misclassified cases is 3 individuals both using DSP2 and using Function 1. Misclassification increases for F3 and F4 which are the functions using only 4 variables.

Table 4 here

Posterior probabilities (PP) of correct classification using DSP2 and F1-F4 for 95 individuals are illustrated in Figure 1. The number of cases is selected with the criterion to be able to compare all functions which means that some fragmented os coxae (not possible to calculate F1 and F2) were excluded. In general DPS2 gave very good results similar to the F1 and F1 functions. In two cases (case 77 and 89) DPS2 gave probabilities less than 95% but F1 and F2 classified these two cases with over 95% probability of correct classification. On the other hand three cases (85, 86, 87) failed to pass the threshold of 95% probability using F1-F4 functions but DSP2 classified them correctly with over 95% probability of correct classification.

Figure 2 illustrates a plot of the discriminant score for functions F1-F4 against the corresponding posterior probabilities of correct group membership. For example if F4>1.2 the unknown individual is assigned as male with over 95% probability of correct classification. Please note that DPS2 does not provide the discriminant scores to the user thus the values could not be included in Figure 2.

Discussion

Methods to estimate sex from skeletonised remains vary significantly in skeletal element, statistical approach and sample selection. Scholars agree that pelvis is consistently different between males and females with a special shape of the female pelvis to facilitate birth [1,7]. Metric sex estimation methods have proven to be population specific which means that in order to use them one must know the ancestry of the unknown skeletal remains. This however is rarely the case in skeletonised bodies especially in the new era of globalization [23,24]. Likely the dimensions of the os coxae are significantly different between males and females in every population that is so far studied. This study explores sexual dimorphism of the pelvis in a Greek population and the applicability of DSP2 software in sex estimation.

DSP2 software used 10 variables and DFA statistical method to infer sex from unknown skeletal remains. As already shown in the original publication concerning DSP [25], the reference dataset meets the assumptions of normality and equality of covariance matrices. The selection of different variables gives different classification results with the best combination of variables to achieve 90% accuracy with over 95% probability of correct classification. A sample of 133 os coxae from the Cretan collection [26] was used to validate DSP2. Nine out of ten variables were found to different significantly between the sex groups. Classification accuracy using DSP2 software with a 95% probability threshold reached 85.7%. This is slightly lower than the validation study of DSP2 by Brůžek and colleagues [1] who reported 90% accuracy for a mixed sample of individuals of US and Swiss ancestry. The data was further analysed and four discriminant functions were produced for the Greek sample. F1 used all ten variables and resulted in 87.6% classification accuracy at the 95% probability threshold which means and population specific formulae improved the accuracy by only 2%. This improvement is not significant and it was somehow anticipated since the accuracy is based on the original sample and not on a validation sample. It is worth noting than in a few cases where DSP2 was inconclusive giving estimates with less than 95% probability of correct classification, the population specific formulae classified it with over 95% probability.

The results clearly indicate that pelvic morphology is consistently different between males and females across populations as proposed by other studies[1,7] and confirm the suitability of sex for the Greek population. Previous studies on the pelvic morphology in Greeks have also detected sexual dimorphism in the pelvis, os coxa and sacrum with the os coxa using a different set of measurements[27]. The authors indicate that classification accuracy of the os coxa can reach 95.4% but they do not calculate the accuracy at the 95% probability threshold. The study also concludes that the entire pelvis is less accurate than the os coxa and suggests it is not worth any time and effort to articulate and measure the pelvic girdle. A second study on the pelvis examining the morphological features of the surface and the shape of the greater sciatic notch on the same skeletal sample gave poor results [28]. Other studies of sexual dimorphism on the Greek population that calculate accuracy at the 95% probability threshold involve the cranium[26], the humerus [3], the tibia [4,29] the scapula and clavicle [30]. Both cranial and postcranial elements present higher overlapping between the sexes compared to the os coxa resulting in significantly lower accuracy with 95% probability of correct classification. For example the best function of sex estimation for the tibia can reach this threshold only for 44.6% of the sample[29].

Taking into account the better performance of the pelvic bone in terms of accuracy at the 95% probability level and the fact that the method is non-population specific as proven in this study we recommend the use of DSP2 as a method of choice in sex estimation of unknown skeletal remains. Other methods should also be applied if available but if the ancestry of the individual is questionable the results of the pelvic assessment using DSP2 should bear more weight in the final sex estimate. In cases that ancestry is reliably assessed, population-specific methods should supplement DSP2 to increase the reliability of the estimate.

Conclusion

Sexual dimorphism of the pelvis is non-population specific and DSP2 software is deemed appropriate for sex estimation in a Greek sample reaching 85.6% accuracy with over probability of correct group assessment. DSP2 is highly recommended as method of choice in estimating sex from unknown skeletal remains. If ancestry is known it should be complemented with appropriate population-specific studies.

Conflict of interest

The authors declare no conflict of interest

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Figure legends

Figure 1. Posterior probabilities of correct classification for DSP2 and F1-F4 for the Greek sample.

Figure 2. Posterior probabilities (Y axis) of the Greek formulae F1-F4 and the corresponding discriminant scores (X axis).

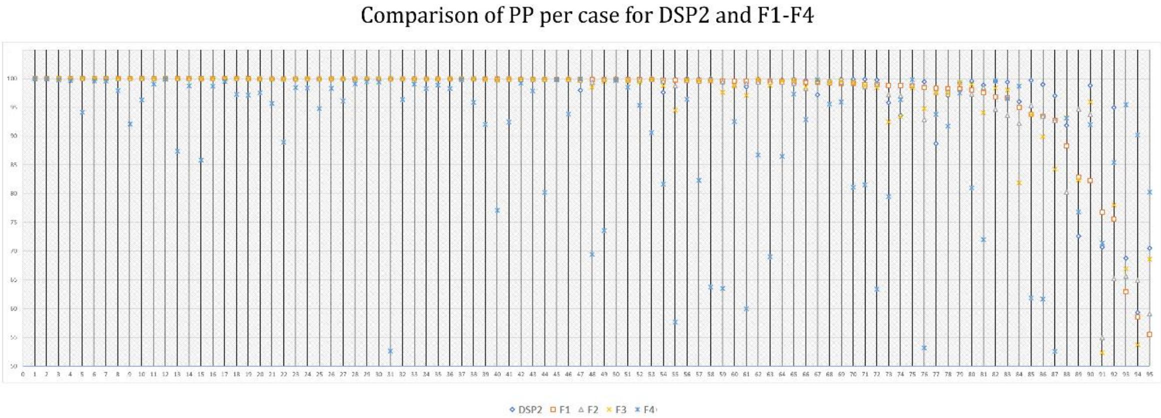

Figure 1

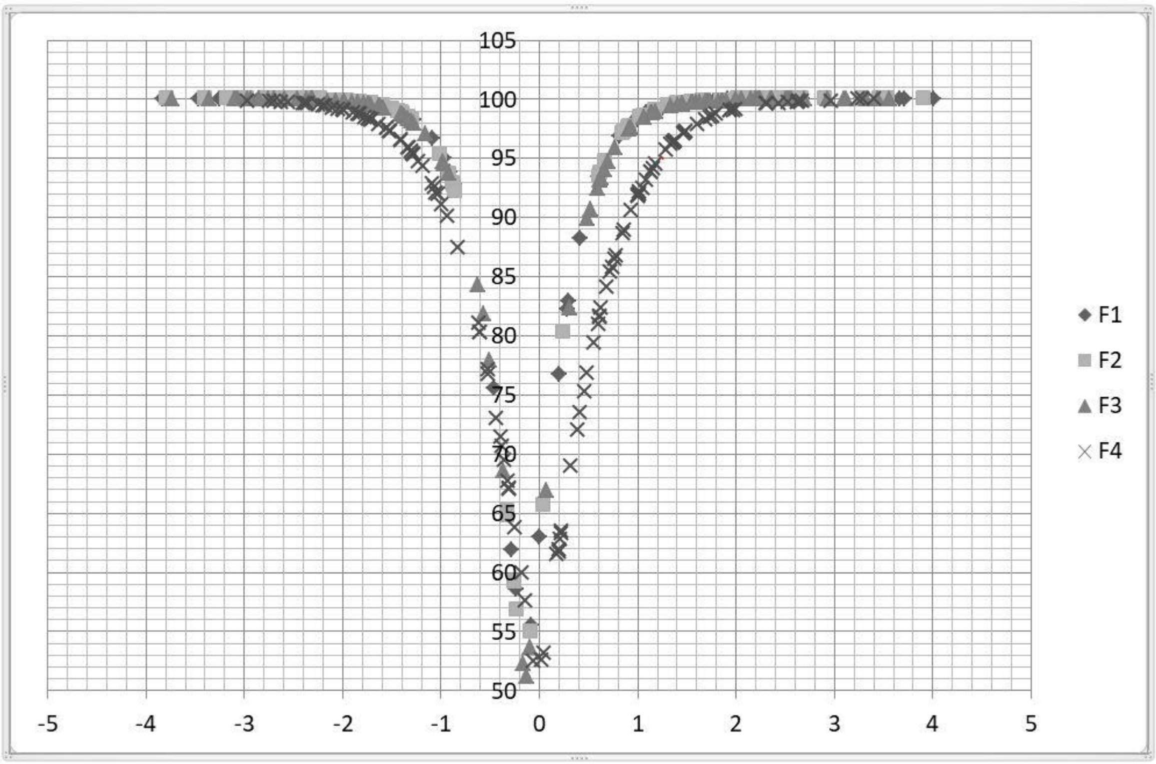

Figure 2.

Table 1. Inter-observer error estimated using the Technical Error of Measurement (TEM), the relative TEM(rTEM) and the coefficient of reliability (R).

	TEM	*r*TEM	R
Pum	0.35	0.48	0.99
Spu	0.29	1.07	0.98
Dcox	2.85	1.36	0.93
Iimt	1.51	3.54	0.94
Ismm	0.98	0.88	0.97
Scox	0.31	0.20	1.00
Ss	0.66	0.90	0.97

Sis	0.86	1.07	0.99
Veac	0.99	2.55	0.91
Sa	0.62	1.05	0.97

Table 2. Descriptive statistics, demarking points and classification accuracy for single variables.

	Descriptives				p-value	Demarking point	% Classification Accuracy	
V	**sex**	**N**	**Mean**	**SD**			**Original**	**LOOCV**
Ismm	M	66	113.95	4.96	<0.001	108.75	86.4	86.4
	F	63	103.55	5.16			85.9	85.9
Spu	M	66	28.45	2.19	<0.001	26.60	81.8	81.8
	F	64	24.74	2.12			84.6	84.6
Dcox	M	66	212.73	9.78	<0.001	204.93	81.8	80.3
	F	64	197.13	8.33			84.6	84.6
Veac	M	67	59.64	3.71	<0.001	56.80	76.1	76.1
	F	63	53.96	2.87			85.9	85.9
Pum	M	62	70.79	3.82	<0.01	71.87	61.3	61.3
	F	51	72.79	4.18			67.3	67.3
Iimt	M	63	39.56	4.56	<0.001	41.84	69.8	69.8
	F	63	44.26	5.01			70.3	70.3
Scox	M	62	156.15	7.11	<0.001	153.87	61.3	61.3
	F	58	151.48	6.59			55.9	55.9
Ss	M	68	74.95	4.26	<0.001	71.50	75.0	75.0
	F	63	68.00	3.96			78.1	78.1
Sis	M	62	41.13	3.11	<0.001	77.60	75.8	75.8
	F	62	36.52	2.61			77.8	77.8
Sa	M	67	76.57	4.78	0.127	77.37	61.2	61.2
	F	63	78.06	6.23			50.0	50.0

Table 3. Multivariate discriminant functions and classification accuracy for original and LOOCV data.

Variables	F1	F2	F3	F4
Pum	-0.148	-0.158	-0.160	
Spu	0.200	0.205	0.229	0.235
Dcox	0.004	0.004		-0.026
Iimt	-0.074	-0.082	-0.090	
Ismm	0.162	0.168	0.168	0.155

Scox		-0.010	-0.016		
Ss		0.059	0.041		
Sis		0.042	0.042		
Veac		-0.051	-0.049		0.053
Sa		-0.035			
Constant		-8.540	-9.033	-9.112	-20.818
% Classification Accuracy					
Original	Males	96.2	94.3	94.7	90.6
	Females	97.8	97.8	94.0	87.3
	Total	96.9	95.9	94.4	89.0
LOOCV	Males	92.5	94.3	94.7	90.6
	Females	91.1	91.1	92.0	87.3
	Total	91.8	91.1	93.5	89.0

Table 4. Posterior probabilities of correct classification for DSP2, and functions F1-F4.

	>95% PP						>50% PP			
	*Sex rate		*Accuracy		Error		Accuracy		Error	
DSP2	117/133	88.00%	114/117	97.43%	3/117	2.57%	130/133	97.70%	3/133	2.30%
F1	88/98	90.00%	86/88	97.73%	2/88	2.27%	95/98	96.90%	3/98	3.60%
F2	87/98	88.78%	85/87	97.71%	2/87	2.29%	94/98	95.90%	4/98	4.10%
F3	91/107	85.10%	91/91	100 %	0/91	0 %	101/107	94.40%	6/107	5.60%
F4	69/127	54.33%	67/69	97.11%	2/67	2.89%	113/127	89%	14/127	11%

*Note that for this table we followed the definitions of the original publication for consistancy :% sex rate: percentage of specimens for which the sex is estimated ($p \geq 0.95$); "% accuracy": percentage of specimens correctly determined.